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Geology and Paleontology Along Part of the Niobrara River in Northern Nebraska

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Nebraska Geological Society Field Trip 2017

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August 5-6, 2017

I. FIELD TRIP SCHEDULE (APPROXIMATE)

<u>Day 1 (August 5, 2017)</u>

8:00-8:15 (0.25 hour) Meet in the Bomgaar's parking lot in Valentine, Nebraska; introductory remarks (drive time to next site 0.25 hour).

8:30-9:30 (1.0 hour) STOP 1—Valentine Railroad Bridge: park and hike on Cowboy Trail and introduce regional geology, geologic history, and geomorphology. Discuss paleontological significance of Ogallala Group strata and Valentine Railway Quarries near bridge. Proceed to Fort Niobrara National Wildlife Refuge (drive time 0.33 hour).

9:50-11:50 (2.0 hours) STOP 2—Fort Niobrara National Wildlife Refuge and Fort Falls: park and hike to Fort Falls, then hike downslope to Niobrara River and eastward along south bank. Outline Paleogene and Neogene stratigraphy and talk about hydrology along the river. Discuss stratigraphic successions on north and south sides of Niobrara Valley (Rosebud, Valentine, and Ash Hollow formations, "Connely Flat beds," etc.). Discuss results of CSD StateMap geologic mapping, including wireline coring of sub-Ogallala Group strata, during 2015-2017. Discuss ecological significance of the Niobrara Valley. Proceed to Rocky Ford Outfitters south of Sparks, Nebraska (drive time 0.5 hrs).

12:20-1:20 (1 hour) STOP 3—Rocky Ford Camp and Outfitters: eat lunch and observe opaline silica-cemented sandstone near base of Valentine Formation. Proceed to Norden Bridge on River Road (drive time 0.15 hour).

1:30-2:00 (0.5 hour) STOP 4—Norden Bridge Quarry and Surrounding Area: discuss local Paleogene, Neogene, and Quaternary geology and geomorphology. Brief commentary on paleontological significance of Norden Bridge Quarry. Proceed to vicinity of Springview, Nebraska (drive time 1 hour).

3:00-3:15 (0.25 hours) STOP 5—Springview Table and Niobrara River Valley: outline local geomorphology and examine Paleogene and Neogene stratigraphy. Discuss significance of Broadwater (= "Long Pine") Formation. Proceed to Rick Irwin Site southeast of Springview (drive time 0.3 hour).

3:35-4:20 (0.75 hour) STOP 6—Rick Irwin Paleontological Site: discuss regional and global changes during the late Miocene. Outline significance of this site and nearby volcanic ash unit. Proceed to Johnstown, Nebraska (drive time 0.9 hr).

5:15-6:00 (0.75 hours) STOP 7 (D&L Gravel pit at Johnstown, Nebraska): discuss fluvial sedimentology, provenance of gravels, and paleontology of Broadwater (= "Long Pine") Formation. Proceed to Valentine, Nebraska (drive time 0.75 hour).

6:45 END OF FIRST DAY: arrive in Valentine, Nebraska.

Day 2 (August 6, 2017)

9:00 am INTRODUCTION AND SAFETY INSTRUCTION at Graham Outfitters, 603 East "C" Street in Valentine, Nebraska.

9:30 am LAUNCH CANOES at Fort Niobrara launch site near Cornell Dam.

9:30 am-3:30 pm FLOAT NIOBRARA RIVER. There will be multiple, informal, group stops along the river to observe geology and geomorphology, including a final stop at Smith Falls.

4:00 pm END OF SECOND DAY. Take out canoes at Smith Falls State Park. End of field trip. Depart for home.

II. OVERVIEW OF FIELD TRIP AREA

1. The Niobrara River and its Valley

The ~440 mile-long (~715 km) Niobrara River and its valley (Fig. 1) are of significant interest from scientific, economic, and recreational standpoints. Unlike certain well-known large rivers that cross the Great Plains (such as the Missouri, North Platte, and South Platte rivers), but like the Republican River some 275 to 300 km to the south of it, the Niobrara River originates on the High Plains, rather than in the Rocky Mountains.

Some of the salient attributes of the *Niobrara River* are:

1. *Possession of but a few large tributaries*. And this despite the river's drainage-basin area of approximately 12,800 mi^2 (33,150 km^2).
2. *Comparatively steady year-round baseflow*. This study evinces the strong and persistent hydrologic connection of the river with the High Plains aquifer. Indeed, the High Plains aquifer can be seen to discharge from the walls of the valley in many places as seeps and springs. A comparison of yearly discharge patterns between the Niobrara River and another, more typical river in Nebraska (Fig. 2) illustrate this point.
3. *Relatively constant water-surface elevation through the year.* This attribute, noted by Buchanan and Schumm (1990), may be appreciated in serial visits to the river.
4. *Rare flooding.* Floods are infrequent and minor overall along the Niobrara River, although local ice-jam flooding is known to occur (Fischer, 1987).
5. *Appreciable changes in river planform (the pattern of channels, bars, and stable islands) since ca. 1854.* These changes can be associated to varying degrees with intensified land use and engineering. Channel width decreased in many places on the Niobrara River after 1870 and the braiding index of the river is now overall less than it was at the time of

the first aerial photographs ca. 1938-1941. The dynamics and morphology of the Niobrara River near and at its mouth have changed substantially since the impoundment of Lewis and Clark Lake on the Missouri River in the late 1950s, enough so to make it the focus of a commonly-cited comprehensive sedimentological study (Bristow et al., 1999).

Some of the salient attributes of the *Niobrara River Valley* are:

6. *Deep incision in recent geologic times.* In the field trip area, the river flows within a steep-sided canyon or bedrock gorge, along which multiple Pleistocene-Holocene terraces can be seen at different topographic positions. The Niobrara River eroded through unconsolidated sediments and eventually became incised into the underlying bedrock strata during the late Pleistocene, probably after 27,000 years ago, and possibly much more recently (cf. Larson, 2001; Jacobs et al., 2007).
7. *Possession of numerous tributary waterfalls.* There are scores of small waterfalls in the Niobrara River Valley, the highest being Smith Falls, Nebraska's highest waterfall, which reaches approximately 70 ft (21 m) in height. Waterfalls in the valley are prominent knickpoints that can be related to the history of incision and regional bedrock stratigraphy.
8. *Appreciable slope-aspect related partitioning of plant communities and other biological attributes.* Bessey (1887) was probably the first botanist to write of the biological uniqueness of the valley. There are close relationships between plant communities and local physical conditions within the Niobrara River Valley. Slope aspect (e.g., north- vs. south-facing slopes, the presence of permeable or impermeable strata, and soil characteristics clearly determine where species (e.g., the paper birch and associated cool-

forest understory species) thrive at a fine spatial scale (Hearty, 1978; Kantak, 1995). The valley is a biological refugium from Pleistocene glacial times and also a migration corridor across the Great Plains for species that are normally associated with boreal and cool-temperate forests in North America (Kaul et al., 1988; Kantak and Churchill, 1993).

2. Geomorphology

Landscapes and landforms of the field trip area were shaped by fluvial erosion and deposition, eolian erosion and deposition, and also by periglacial processes (but not glacial processes) during intervals of cold climates during the Pleistocene. The entire course of the Niobrara River lies on the Great Plains, according to a widely accepted definition of that physiographic province, and yet there is a great diversity of landforms within its valley.

The stage was set for the development of the modern landscape with the end of widespread fluvial deposition near the end of the Miocene Epoch. By the end of Ogallala Group times, a vast, low-gradient fluvial depositional landscape stretched across most of Nebraska, and local relief on this depositional surface must have been minor, and certainly less than what is evident on today's landscape. By the end of the Pliocene epoch, the major west-to-east drainage lines—namely the proto-Platte River System—trended east-northeastward across Nebraska and deposited conspicuous gravels and coarse sands, as well as other sedimentary facies, in a broad, linear tract. Skinner and Hibbard (1972) called these sediments the "Long Pine Formation", but they are more appropriately included within the Broadwater Formation. Age control on these sediments is by no means ample, but they are likely to be late Pliocene to early Pleistocene in age, particularly considering that the Pliocene-Pleistocene boundary has been moved to an older position on the geologic times scale (2.588 Ma) in the past decade.

The effects of more geologically recent fluvial erosion are, arguably, the most striking geomorphic effect in the field trip area. The middle Niobrara River Valley attains a maximum depth of approximately 460 ft (140 m), but in many places it is approximately 300 ft (91 m) in depth. The middle Niobrara River produced its present canyon by eroding through unconsolidated Miocene sediments of the Ogallala Group, and eventually through the consolidated siltstones of the underlying Rosebud Formation and, farther to the east, the Brule Formation as well. This incision took place during the late Pleistocene, after 27,000 years ago, and possibly much more recently (cf. Larson, 2001; Jacobs et al., 2007). Fluvial deposition embellished the landscape of the Niobrara River canyon. Multiple late Pleistocene (higher in elevation) and Holocene (very low in elevation and proximal to the present river) can be seen at many places along the canyon. These terraces are broadest (as much as 3 km) and most prominent on the south side of the Niobrara River, at the northern margin of the Sand Hills, and there has been widespread eolian reworking atop those terraces. There are, nevertheless, terrace remnants along the north side of the river, including multiple, particularly prominent late Pleistocene terraces in the Norden, Nebraska area. Pleistocene terrace deposits on the Niobrara River can be recognized on the basis of their gravels, which include common clasts eroded from Miocene strata within the basin as well as Rocky-Mountain-sourced crystalline lithologies. Terrace deposits are overall coarser than the unconsolidated sands of the Ogallala Group, with which they might otherwise be confused by an uninitiated observer. Some of the local tributaries entering the Niobrara River from the north also exhibit multiple high terraces as they transect the deeply incised canyons on the north side of the river. Big Beaver Creek, northeast of Valentine, Nebraska, has at least four high terraces, and probably more (Joeckel et al., 2016).

Late Pleistocene eolian erosion has a subtle but pervasive signature in the uplands north of the Niobrara River, where most of the landscape exhibits prominent northwest-to southeast-trending low, elongate ridges and valleys. Even the rim of the Niobrara river's canyon—the outcrop of the Cap Rock Member of the Ash Hollow Formation—exhibits crenulations oriented in the same matter. We interpret the northwest-southeast "grain" of the landscape as the result of erosion of bedrock and surficial sediments by strong winds during the Pleistocene. The low, elongate ridges in the uplands, eroded from the Ash Hollow and Broadwater formations, are, therefore, relict yardangs. The role of eolian erosion in shaping the regional landscape is gradually being revealed by ongoing geologic mapping.

Pleistocene and Holocene eolian depositional landforms—chiefly dunes of various forms and sizes—can be found on both sides of the Niobrara River, and dunes of reworked alluvial sand nearly abut the river's course in places. Most of the area of diverse, larger dunes included within the established boundaries of the Nebraska Sand Hills lies to the south of the Niobrara River (Swinehart, 1998). The Sand Hills is the largest dune field in the Western Hemisphere. Large dunes in the Sand Hills migrated multiple times during the past 10,000 years in response to severe drought, including as recently as recently as ~700 years ago (Miao et al., 2007). The Cobb and Wobig basins, south of Cody and Merriman in Cherry County, Nebraska, are stretches of the ancient Niobrara River that were blocked by migrating sand dunes (dune dams) and filled with lake sediments, which are locally fossiliferous, between ~45,000 and ~27,000 years ago (Jacobs et al., 2007). These deposits are high above present river level.

Relict periglacial polygonal ground—the product of thermal contraction cracking in formerly permafrosted terrain—was identified in dozens of places around the middle Niobrara River, and mostly on the broad divide between the Niobrara and Keya Paha rivers, during close examination of aerial photography by Joeckel and others in 2016. This relict polygonal ground exists in fields as large as 65 ha on comparatively stable, flattish upland surfaces in the middle Niobrara River and Keya Paha valleys in Boyd and Cherry counties in Nebraska, and northwestward toward St. Francis, South Dakota (Figs. 3,4). The sites at which relict polygonal ground has been found lie north of approximately 42.8° N latitude and between approximately 99.7° and 100.9° West longitude. The relict polygonal ground consists of irregular pentagons, hexagons, and heptagons 4 to 50 m in maximum width (Figs. 3, 4). This recent and as-yet unpublished discovery indicates that periglacial conditions—cold but not glacial and distinguished by the presence of permafrost—existed in the area during Wisconsinan times, presumably at about the time of the Last Glacial Maximum, when the Laurentide Ice Sheet had advanced within 75 to 150 km northeast of the middle Niobrara River Valley. The examples of relict polygonal ground in the study area are the clearest and most widespread evidence yet found for ancient periglacial conditions in Nebraska.

The United States Department of Agriculture Natural Resources Conservation Service (2006) recognizes three Major Land Resource Areas within the area of the field trip (Fig. 5): (1) the Nebraska Sand Hills, (2) the Dakota-Nebraska Eroded Tableland, and (3) the Southern Pierre Shale Plains (of these, only #1 and #2 will be viewed during the trip). The Nebraska Sand Hills are widely recognized as a unique area, with slight variations in mapped extent, by many geologists and other scientists. The other two MLRAs are not widely recognized among geologists, but their definition is scientifically sound from the perspective of regional geology and geomorphology. Soils in the field trip area range in texture from clayey to sandy and parent materials are likewise diverse, ranging from weathered Upper Cretaceous Pierre Shale to Pleistocene-Holocene dune sands (Fig. 3). The most widespread soil parent material in the field trip area is eolian sand, which dominates south of the Niobrara River in the Nebraska Sand Hills (Figs. 3, 5). Sandy to loamy soils on a variety of parent materials dominate north of the river.

3. Pre-Pleistocene Geology

All of Nebraska lies on the North American platform, which is the tectonically stable part of the continent under which a relatively thin cover of sedimentary rocks overlies Precambrian basement, that is, deep, most generally igneous and metamorphic rocks that are a billion years old or older. The basement of North America is a large-scale patchwork of rocks ranging in ages from older than 2.5 billion years to approximately 1.0 billion years old. Northernmost Nebraska, southern South Dakota, and eastern Wyoming are underlain by four distinct basement terranes—the Wyoming craton in the west, the Trans-Hudson and Central Plains orogens in the middle, and the Superior craton in the east—albeit at comparatively great depths below the present land surface. The Central Plains Orogen (Sims and Peterman, 1986; Van Schmus and Bickford, 1993) underlies most of northern Nebraska and a large portion of interior USA. This orogen is an association of various basement rock types that was sutured to the growing North American continent by collisional plate tectonics between roughly 1.6 and 1.8 billion years ago. We can very logically assume that there was very intense geologic activity—including strong earthquakes, plutonism, volcanism, and mountain-building—in northern Nebraska during this distant interval of geologic time. Following the Proterozoic Eon, the study area was covered by successive increments of Phanerozoic sediment in response to regional tectonics and sea-level changes.

The structural and tectonic setting of north-central Nebraska and adjacent southern South Dakota are known in broad terms only. The field trip traverses the eastern side of the southern part of the poorly defined Kennedy Basin, which itself lies between two areas that experienced epeirogenic uplift during the Paleozoic and possibly intermittently thereafter: the Chadron Arch (or Chadron-Cambridge Arch) to the west and the Siouxana Arch to the east, which barely extends into the southeastern part of the field trip area (Fig. 6). Several authors agree that the Chadron Arch and other gentle structures on the Great Plains were reactivated during the Laramide orogeny (Condra et al., 1950; Swinehart et al., 1985; Bunker et al., 1988; Tikoff and Maxson, 2001). All of the aforementioned features lie along the poorly-defined, very broad, northeast-to-southwest structural feature known as the Transcontinental Arch, which appears to have exerted a persistent tectonic influence in the continental interior through much of the Paleozoic (Billo, 1985; Carlson, 1999). The basinal region of this arch between the component Chadron and Siouxana arches is referred to as the Nebraska Sag by some authors (e.g., Carlson, 1999).

Deeper subsurface stratigraphy in north-central Nebraska is known only from a comparatively small number of petroleum wells. The #1 Borman Cattle well (API #26031050190000), a dry hole drilled just southeast of Valentine, Nebraska, encountered Precambrian basement rocks at -631 ft or -192 m MSL, after penetrating Cretaceous, Jurassic, Permian, and Pennsylvanian strata; Paleozoic strata older than Pennsylvanian appear to be absent in the subsurface at this location. As much as 3200 ft or 914-975 m of Phanerozoic sediments and sedimentary rocks overlie Precambrian basement in the Valentine area. To the east, the #7-5 Wolbach well (API #26017210020000), also a dry hole, was drilled approximately 6.2 mi or 10 km south of Norden, Nebraska, and it penetrated slightly more than 2700 ft or 823 m of Phanerozoic sediments and sedimentary rocks, encountering the weathered top of Precambrian basement rocks at -384 ft or –117 m MSL. Northeast of Burton, Nebraska, near the eastern edge of the field trip area, the #B-1 Baker well (API #26103210050000) penetrated 2418 ft or 737 m of Phanerozoic sediments and sedimentary rocks and encountered the top of Precambrian basement rocks at -297 ft or –91 m MSL.

Sediments and sedimentary rocks ranging from late Eocene to Holocene in age are exposed in the middle Niobrara River Valley (Figs. 7-9). The Upper Cretaceous Pierre Shale is exposed at the eastern end of the field trip area (Fig. 7), being visible south of Springview, Nebraska in the lower slopes of the Niobrara River Valley, and around the confluence of Plum Creek and the Niobrara River, and it underlies the aforementioned Cenozoic deposits to the west. According to Skinner et al. (1968), Skinner and Hibbard (1972), and Skinner and Johnson (1984), the composite Paleogene-lower Pleistocene succession (Fig. 8) in north-central Nebraska (including all of Cherry County) is, in ascending stratigraphic order: (1) the upper Eocene-lower Oligocene White River Group, consisting of the Chadron and Brule formations; (2) the middle Oligocene-lower Miocene Arikaree Group, consisting of the Gering (in the subsurface only) and Harrison formations in western Cherry County (plus an outlier of the latter near Kilgore), and the Monroe Creek and Rosebud formations in the central to eastern parts of the county—the regional composite succession being Gering, Monroe Creek and Rosebud, and Harrison formations (Skinner and Johnson, 1984); (3) the middle to upper Miocene Ogallala Group, consisting of the Valentine and Ash Hollow formations, and (4) the Pliocene (?) and lower Pleistocene Keim, “Long Pine,” “Pettijohn,” and “Duffy” formations (Skinner and Hibbard, 1972), the “Long Pine” Formation now being considered to be the Broadwater Formation that was originally recognized in western Nebraska (Schultz and Stout, 1945; Swinehart and Diffendal, 1998), and the latter two formations now being generally disregarded. The significance of this succession is discernible in the composite Cenozoic section for Nebraska (Fig. 9). In the field trip area, however, local stratigraphic successions are less complete, although the Rosebud, Valentine, and Ash Hollow formations are widespread in the field trip area, and the Chadron Formation may be more widespread in the subsurface than the sparseness of outliers suggest.

The regional Neogene succession is dominated by sandy fluvial deposits (Fig. 9). The Chadron, Brule, and Rosebud formations are, overall, dominated by claystones to siltstones, some of which have a significant component of primary or secondary airfall sediment (volcanic ash and other dust). The Rosebud Formation, in particular, has a loess-like aspect in many places. CSD's wireline core drilling in the Sparks, Nebraska area during 2016 (Fig. 10) established for the first time that the total thickness of late Eocene and Oligocene sediments of the White River and Arikaree groups is approximately 397 ft or 121 m in total thickness in eastern Cherry County. Furthermore, the total thickness of Miocene sediments of the Ogallala Group in that area is at least 240 ft or 73 m and, therefore, the entire Cenozoic succession is at least 637 ft or 194 m in thickness (Joeckel et al., 2016).

Several weak earthquakes have been recorded in the general area of the field trip during historical times, and specifically from the 1930s onward (Fig. 6). These earthquakes emanate from the reactivation of structural features in Phanerozoic sedimentary rocks at depth and in the basement. A magnitude 5.1 earthquake with an epicenter near Merriman, Nebraska, 58 mi (93 km) west of Valentine occurred on March 28, 1964. This earthquake was felt in parts of four states and caused minor damage (United States Geological Survey, undated). During the period 2005-2010, there were three weak earthquakes of magnitude 2.9 or less in the eastern part of the field trip area.

4. Hydrogeology

The High Plains aquifer is present in most of the field trip area, but absent in parts of deeply incised valleys (Fig. 11). The aquifer is hosted chiefly by the Ogallala Group and Quaternary fluvial and eolian sediments, although there may also be groundwater in the upper Brule, Gering, Monroe Creek, Rosebud, and Harrison formations (Fig. 9). The role of the Rosebud Formation in regional hydrogeology should be investigated in the future, because sands within that formation bear water but its massive siltstones may function as aquitards. The water table in the field trip area declines generally east-northeastward and the saturated thickness of the High Plains aquifer is less, and also more variable, north of the Niobrara River. Within 15 mi (24 km) south of Valentine, Nebraska, saturated thickness in the High Plains aquifer attains values of 400 ft (122 m) or greater under the Sand Hills (Fig. 12). Registered irrigation wells are distributed throughout the area and exhibit some degree of clustering in the vicinity of Ainsworth, Nebraska (Fig. 12). Over most of the field trip area, there has been no significant change in water levels since predevelopment times in the field trip area, but long-term groundwater-level declines have occurred in very small areas, such as an area southwest of Bassett (Fig. 13). Mapped areas of slight water-table rise within the field trip area (e.g., south of Valentine, northwest of Ainsworth and east of Springview, Nebraska) are actually much greater in aggregate area (Fig. 13). The High Plains aquifer is easily visualized in the middle Niobrara River Valley not merely because its host strata are exposed therein, but also because of the presence of extensive seeps along the valley walls at the contact between the Rosebud Formation and the overlying Valentine Formation. These seeps frequently freeze in wintertime to form ice falls, which have, in themselves, become a minor recreational draw.

It should be noted that other aquifers lie deeper below the base of the High Plains aquifer in north-central to northeastern Nebraska. The Upper Cretaceous Codell Sandstone of the Carlile

Shale yields groundwater locally east of the field trip area and, likewise, a few wells are developed in the fractured upper part of the overlying Niobrara Formation as well. Much more extensive in area, however, are the Great Plains and Western Interior Plains aquifer systems (Jorgenson et al., 1996). The extents, recharge areas, potentiometric surfaces, and other characteristics of these deeper and more extensive aquifers are related to regional geologic structure and the geologic history of deposition, uplift, and erosion.

Groundwater irrigation in the Niobrara Basin began in 1938 and increased considerably in succeeding decades, but the impact of groundwater withdrawal appears to be comparatively minimal in the field trip area. The few surface-water engineering projects along the length of the Niobrara River have had little effect in comparison with the many more heavily regulated river basins on the Great Plains (Buchanan and Schumm, 1990). During the 1970s and 1980s, research was done to assess the installation of a major dam to impound approximately 411,000 acre-feet or 507,000,000 cubic meters of water on the Niobrara River near Norden, but the project was de-authorized in 1986. The Niobrara National Scenic River was established in 1991.

5. Paleontology

The Niobrara River Valley has yielded a critically important assemblage of late Cenozoic vertebrate fossils over a period in excess of 150 years. F.V. Hayden (1829-1887), serving as a geologist on Lt. G.K. Warren's (1830-1882) Military Expedition, collected fossils from several localities along the river in 1857. Hayden brought these specimens to Joseph Leidy (1823-1891) at the Academy of Natural Sciences in Philadelphia. Leidy (1858) reported on these specimens naming 28 new taxa including antelope, horse, rhinoceros, beaver, and carnivorans. O.C. Marsh (1831-1899), professor at Yale University, led subsequent expeditions to the Niobrara River Valley in 1870 and 1873 (Lindsay, 1931). One of these expeditions collected fossil material from the mouth of Minnechaduza Creek, northeast of Valentine. According to Skinner and Johnson (1984), T.E. Wilcox, a physician with the U.S. Army, gave a small collection of fossils found near Fort Niobrara to Marsh's rival E.D. Cope (1840-1897) around 1890. Today, these specimens are housed at the American Museum of Natural History (AMNH). In 1903, AMNH personnel returned to Fort Niobrara and recovered additional specimens. Unfortunately, these early explorations lack detailed locality and stratigraphic data.

Erwin Hinkley Barbour (1856-1947), director of the University of Nebraska State Museum, sent crews to north-central Nebraska each field season between 1913 and 1917 and between 1928 and 1935. UNSM personnel also conducted a field survey four decades later (1976-1981) to assess potential impact to fossil resources as a result of a proposed reservoir near Norden. Mike Voorhies, emeritus curator of vertebrate paleontology at UNSM, and his students discovered 30 new sites during this survey (Voorhies, 1990).

The majority of our understanding of the geology and vertebrate paleontology of the central Niobrara River Valley, however, is the result of the work of Morris Skinner and his colleagues in the Frick Laboratory at the American Museum of Natural History in New York City. Skinner spent more than 60 years collecting in this area and discovered more than 120 Miocene and Pliocene sites in Cherry, Brown, and Keya Paha counties. Personnel from the University of California, University of Michigan, Michigan State University, University of Notre Dame, Carnegie Museum of Natural History, and Smithsonian Institution also collected fossils from the Niobrara River Valley.

Very few fossils have been recovered from the Rosebud Formation. Skinner et al. (1968) reported the occurrence of four oreodont skulls belonging to *Desmatochoerus* and

Leptauchenia. Voorhies did not recover any fossil material from the Rosebud Formation in the central Niobrara Valley but found the rabbit *Palaeolagus hypsodus*, the small ruminant *Nanotragulus loomisi* (=*N*. cf. *N*. *intermedius* of Voorhies, 1973), and the beaver *Palaeocastor* cf. *P*. *nebrascensis* from the Middlebranch and/or Walnut Bridge localities in Knox County (Voorhies, 1973). We assign the Rosebud fauna to the early Arikareean North American Land Mammal Age (NALMA), specifically the late Oligocene subdivision Ar1 of Tedford et al. (2004), which ranges from 30 to 28 Ma.

Vertebrate fossils from the lower three members of the Valentine Formation fall within the late Barstovian (Ba2 of Tedford, et al. 2004) NALMA ranging from approximately 12.6 to 14.0 Ma. The Burge Member, the uppermost unit within the Valentine Formation, lies within the early Clarendonian (Cl1 of Tedford, et al., 2004) NALMA roughly 12.0 to 12.5 Ma. Fossil remains from the Ash Hollow Formation belong to the medial and late Clarendonian (Cl2 and Cl3 of Tedford, et al., 2004) NALMA, ranging in age from 9.5 to 12.0 Ma. A few late Miocene (Hemphillian-aged) fossils, most notably those from the Rick Irwin site, have been collected from fluvial deposits in the uppermost Ash Hollow Formation. These sites are between 6 and 9 million years old. There are also Pliocene and Pleistocene (Blancan and Rancholabrean NALMAs) vertebrate fossils from the field trip area (Skinner and Hibbard, 1972; Voorhies and Corner, 1985).

In addition to the many vertebrate fossil localities in the middle Niobrara Valley, there is also an important paleobotanical site in the Valentine Formation. MacGinitie (1962) first published on the Kilgore flora, named for a site near Kilgore in Cherry County, Nebraska. The fossil flora seems to represent open and riparian woodlands—but not open grasslands—that grew under seasonal, but not freezing, climates.

III. FIELD TRIP STOPS

STOP 1—Valentine Railroad Bridge. The Valentine railroad bridge is the tallest railroad bridge in Nebraska, standing 140 ft or 43 m above the Niobrara River (Penry, 2012). This steel structure replaced a timber trestle located directly east on the original (1883) railroad grade through what was called the "Big Cut." The original bridge's age, untreated wood, and fire risk, as well as problems with drifting snow and blowing sand were problematic. Moreover, the steepness of the 1883 grade required additional locomotive power of the southward ascent (Penry, 2012). Work began on the present bridge in the spring of 1909 and it was completed in 1910. The last train crossed the bridge in 1992 and the Chicago and Northwestern Line was subsequently turned over to the Nebraska Game and Parks Commission. The railroad bed was then converted into the Cowboy Trail, which is the largest rails-to-trails effort in the USA.

George Bunnell, a local teamster who worked on the construction of the new grade, reported the presence of fossils to a field party from the University of Nebraska State Museum (UNSM) in 1915. UNSM paleontologists worked three separate fossil quarries intermittently from the 1910s into the 1990s. Other institutions, including the University of California at Berkeley, American Museum of Natural History, and Carnegie Museum of Natural History, also excavated in the vicinity of the railroad grade. Furthermore, the Nebraska Highway Paleontology Program salvaged more than 20,000 identifiable specimens during the realignment of U.S. Highway 20 in the 1990s.

Detailed lithologic descriptions of the stratigraphic units exposed in the area are given in Johnson (1936), Skinner et al. (1968), Webb (1969), and Skinner and Johnson (1984), as well as other references. The Rosebud Formation is exposed near river level and is overlain by nearly 250 ft or 76 m of the Valentine Formation (Crookston Bridge, Devil's Gulch, and Burge members; Fig. 14). The Ash Hollow Formation overlies the Valentine Formation, which is capped by the Quaternary “Connely Flat beds” or “High Terrace Gravels” of the Niobrara River.

Disarticulated vertebrate skeletal remains are recovered from unconsolidated sand and locally derived gravels of the Crookston Bridge Member. This 14 million-year-old fluvial deposit preserves elements from nearly 90 species in the Railway Quarries. The number of browsing taxa outnumber grazers, suggesting that the middle Miocene landscape had extensive riparian woodland communities.

We emphasize that good exposures of Ogallala Group strata, except for the Cap Rock Member of the Ash Hollow Formation, are now limited in size and number in the field trip area, even though those materials may be overlain merely by a layer of sod. Photographs in Skinner et al. (1968), Skinner and Johnson (1984), and much older photographs reproduced by Voorhies (1987) indicate that these strata were much more clearly exposed along the Niobrara River in the early to middle 20th century. The entire local succession of the Ogallala Group is traversed in the descent of Nebraska Highway 12 into the Niobrara River Valley near Valentine. The contact between the silty sands of the Cornell Dam Member and overlying sands of the Crookston Bridge Member of the Valentine Formation is clearly exposed along Nebraska Highway 12 approximately 0.13 mi (0.20 km) upslope of the entrance to Fort Niobrara National Wildlife Refuge. Also, there are good exposures of the Cap Rock Member of the Ash Hollow Formation approximately 0.7 mi (1.1 km) upslope on the highway, approximately 0.15 mi (0.24 km) south-southwest of its intersection with the access road leading to the Niobrara River overlook along Nebraska Highway 12.

STOP 2—Fort Niobrara National Wildlife Refuge and Fort Falls. Fort Falls is a scenic highlight of the Fort Niobrara National Wildlife Refuge. Its location indicates a knickpoint (comparatively abrupt change in the gradient of a stream) where a small tributary of the Niobrara River descends into the steep lower part of the valley. There are several falls of varying sizes on the outcrop of the Rosebud Formation (Fig. 14) in the field trip area. These knickpoints result from both the cropping out of the more erosion-resistant Rosebud Formation and from the geologically recent incision of the Niobrara River. Knickpoints along the valley walls will gradually migrate upstream (away from the river) on tributaries as erosion proceeds into the distant future.

Many of the waterfalls on the Rosebud Formation in the Niobrara River Valley— and even the bed of the river where it is eroded into the same unit—exhibit sculpted erosional forms on that soft bedrock material, and a close examination of such feature, whether at Fort Falls, Smith Falls, or elsewhere, is rewarding. These forms include flutes, furrows and chimney furrows, and potholes (see Richardson and Carling, 2005 for terminology and definitions). It is well to remember that bedrock can be eroded by multiple mechanisms besides abrasion, including cavitation in very rapid flows and evorsion, that is, erosion by turbulent stresses in a clear fluid, which is typically relevant only in cases of unconsolidated or poorly consolidated, fine-grained sediments or sedimentary rocks like the Rosebud Formation (Richardson and Carling, 2005).

Immediately downstream of the confluence of the falls and the Niobrara River are large outcrops of the late Oligocene Rosebud Formation (Fig. 14), over which groundwater discharges in extensive seeps (ice falls in wintertime) from the overlying Valentine Formation. These seeps were even more prominent in the early 20th century before vegetation spread over the lower valley slopes of the Niobrara River (Voorhies, 1987). The contact between siltstones of the

Rosebud Formation and sands of the overlying Valentine Formation is visible in the Fort Falls area. The basal part of the Valentine Formation here and elsewhere exhibits large, irregular masses of light gray to greenish gray opaline silica-cemented sandstone ("quartzite" or "orthoquartzite") that are resistant to weathering.

The exact identity and age of all of the strata grouped under the name "Rosebud" in Nebraska and South Dakota, however, have been debated for some time (Martin, 2011), but the strata referred to as the Rosebud Formation in the field trip area form a coherent package in the context of regional stratigraphy and they are likely to be of Oligocene age (Skinner et al., 1968; Skinner and Johnson, 1984; Martin, 2011). In the middle Niobrara River Valley, the Rosebud Formation contains distinctive sedimentary rock types. Massive siltstones with blocky soil structure and frequently also with unusual banding of unknown origin (Fig. 10), may be floodplain fines, loessic deposits, or a combination of both. The distinctive banding present in many exposures of the Rosebud Formation siltstones can easily be discerned in the outcrops downstream from Fort Falls. Cut-and-fill sequences of thin siltstones, sparse sands, and siltstone-clast conglomerates are prominent in a few exposures. These sequences are interpreted to be gully-fill deposits or the deposits of small streams. One exposure of what may be the upper Rosebud Formation in the area of Fort Niobrara National Wildlife Refuge exhibits a comparatively thick (> 3 m) sheetlike sand body with macroform accretion surfaces, which indicate bar accretion within a fluvial channel of modest depth. The stratigraphic architecture, lithofacies composition, and depositional origins of the Rosebud Formation are stimulating ongoing research.

Waterfalls on the outcrop of the Rosebud Formation tend to be convex in shape rather than concave. Darryll Pederson, his student Len Mason, and other researchers in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln examined waterfalls in the Niobrara River Valley in detail during the early 2000s. Pederson et al. (2003) emphasized freeze-thaw weathering and Mason et al. (2004) implicated *salt weathering* (precipitation and hydration of salt efflorescences) as potentially important differential weathering agents in the development of waterfalls on the Rosebud Formation in the Niobrara River Valley.

STOP 3—Rocky Ford Camp and Outfitters. The place name Rocky Ford refers to a prominent knickpoint, in the form of a very short (approximately 75 ft or 23 m) rapids, on the Niobrara River. The rocks at Rocky Ford are opaline-silica-cemented sandstones of the basal Valentine Formation—the most resistant rock exposed in the middle Niobrara River Valley. The rapids span the river's channel at a light constriction and they are approximately 120 ft or 37 m in width. They are located in the crossover zone between two large meanders. Upstream of Rocky Ford, the river is typically less than 200 ft or 61 m in width. Significant changes in the width and planform are apparent on the Niobrara River downstream of Rocky Ford. In-channel and alternate (channel-side) compound bars, as much as 700 ft or 213 m in length, are prominent downstream of this location. Also, the river is generally wider, attaining a maximum width of more than 1,200 ft or 366 m between Rocky Ford and the crossing of Meadville Road to the east. One salient exception to this widening is at Norden Bridge, where the Niobrara River passes through a very narrow chute eroded into the siltstones of the Rosebud Formation. In comparison with the river's upstream stretches, the Niobrara River is wider (typically, at least twice as wide) and it has a decidedly braided appearance from a point approximately 3.5 miles or 5.6 km southeast of Rocky Ford eastward to its mouth.

STOP 4—Norden Bridge Quarry and Surrounding Area. The Norden Bridge area is geologically significant for multiple reasons. The bridge itself crosses a very narrow chute, approximately 600 ft or 183 m in length, eroded into the slightly resistant Rosebud Formation. Flow width is greatly constricted at the chute to only 60 ft or 18 m, while flow velocity and depth are obviously greater than upstream of the chute. The width of the river's channel short distances upstream and downstream of the chute is 400 to 500 ft or 122 to 152 m, that is, between six and nine times the width of the chute. The knickpoint of the chute has retreated westward nearly 400 ft (122 m) in 35 years. There appears to be a relationship between the position of the chute and the orientation of joints within the Rosebud Formation, thereby suggesting a structural control on the feature.

In 1929, Morris Skinner—a graduate of the University of Nebraska-Lincoln—discovered Norden Bridge Quarry while working for the American Museum of Natural History. The University of Michigan, University of Notre Dame, Michigan State University, Smithsonian Institute, and the University of Nebraska State Museum have sampled the site since then. Basal Valentine sediments record an ancient stream system that flowed generally northwest to southeast. These sediments fill a channel incised into the Rosebud Formation and they incorporate siltstone rip-up clasts and large blocks from the latter formation. The site is capped by Pleistocene terrace sands and gravels.

Norden Bridge Quarry is known predominantly for its microvertebrate fossils. Voorhies (1990) reported that the University of Nebraska State Museum collected more than 83,000 fossils with 95% of these representing taxa weighing less than 22 lbs or 10 kg. This middle Miocene fauna is considered to be slightly older than others (i.e. the Railway Quarries) in the basal Valentine Formation on the basis of the stage of evolution in the fossil species it contains.

Voorhies (1990) reported 144 taxa (excluding birds), making it the most diverse Neogene locality in all of North America. The lower vertebrate fauna contains alligator gar, alligator snapping turtle, giant tortoise, alligator, and several species of snake. Giant salamander remains suggest a cold, fast-moving, rocky bottomed river (Fig. 15). Mammals include eight different bone-crushing dog, horses, rhinoceros, tapir, four-tusked elephant, camel, and many ruminants including small antelope, saber-toothed deer, three-horned "deer" (Fig. 15). The mammalian community includes more browsers than grazers, suggesting the landscape was more wooded than those preserved in younger stratigraphic units.

The geology at the site is representative of the surrounding stretches of the Niobrara River. The outcrop of the Rosebud Formation continues along the south side of the river and the channel is covered by a high Pleistocene terrace. Small dunes on the terrace surface give way continuously to the larger dunes of the Nebraska Sand Hills to the south. To the northwest, across the Niobrara River, a particularly prominent tread of a high Pleistocene terrace is visible. That terrace lies some 170 ft or 52 m above present river level. In June 2017, the Conservation and Survey Division drilled a 288 ft or 88 m wireline core at the top of the terrace under which the Norden Bridge Quarry lies. That corehole fully penetrated the Paleogene succession, which is approximately 25% thinner than in the Sparks area. Very slightly weathered Pierre Shale was encountered at the bottom of the corehole.

STOP 5—Springview Table and Niobrara River Valley near Springview Nebraska.

The town of Springview, Nebraska is located atop a very prominent, flat table that is underlain by fluvial sands and gravels of the Broadwater Formation (= "Long Pine Formation" of Skinner and Hibbard, 1972), as well as the Ogallala Group and underlying strata. The Springview Table can be thought of as a relict late Pliocene or early Pleistocene fluvial depositional surface around which dissection has occurred. Loamy surface soils atop the table are interpreted as evidence for minor loess deposition during the late Pleistocene.

Skinner and Hibbard (1972, fig. 3) and Skinner and Johnson (1984, fig. 37) documented the existence of the Chadron Formation of the White River Group in road cuts along the east side of U. S. Highway 183 south of Springview and approximately 1.2 to 1.6 mi (2 to 2.5 km) road miles north of the north bank of the Niobrara River (Fig. 16). In the immediate area, massive, blocky weathering claystones of the Chadron Formation are directly overlain by the Rosebud Formation of the Arikaree Group, and the Valentine and Ash Hollow formations of the Ogallala Group are exposed farther upslope. Skinner and Hibbard (1972) and Skinner and Johnson (1984) documented the existence of White River Group strata in the area, although they were recognized as early as 1955. Nevertheless, the geological community is largely unaware that there are multiple small outliers of the Chadron Formation in north-central Nebraska. Underneath the Chadron Formation, the weathered upper part of the Upper Cretaceous Pierre Shale is largely covered by vegetation.

STOP 6—Rick Irwin Paleontological Site. The Rick Irwin Site was discovered during highway construction in 1992. Abundant fragmentary late Miocene vertebrate fossils were collected here from a small channel fill consisting of unconsolidated sand and gravel within the upper Ash Hollow Formation. These fossiliferous gravels consist of reworked sandstone, siltstone, abundant rhizoliths, and occasional ash clasts. Reworked clasts of the Blacktail Creek ash define the lower age limit for the site at 6.6 Ma. Basal gravels of the post-Miocene Broadwater Formation ("Long Pine Formation" of Skinner and Hibbard, 1972) cap the site and surrounding area. Paleontologists have collected more than 15,000 identifiable vertebrate fossils through the dry screening of uppermost Ash Hollow Formation sediments here. An assemblage of large and small taxa suggest an overall late Hemphillian age (6.0-6.6 Ma) for the site. The fauna contains many taxa that are rare in the central Niobrara River Valley and it is one of the most diverse sites of its age in North America. Tucker (2004, 2014) described seventeen carnivore species including two felids, five canids, nine mustelids, and one procyonid. Fifteen insectivores including at least three new species are represented in the fauna (Tucker and Voorhies, 2005). The Rick Irwin site is significant in that it records life on the Great Plains at the beginning of a time of widespread climatic and landscape change near the Miocene-Pliocene boundary.

STOP 7—D&L Sand and Gravel Pit near Johnstown, Nebraska. At least 30 to 50 ft or 9 to 15 m of cross-bedded sand and gravel in the Broadwater (= "Long Pine") Formation are exposed in the walls of the D&L Sand and Gravel Pit north of Johnstown. A minimum of 40 ft or 12 m of sand and gravel exist below water level in the pit. Skinner and Hibbard (1972) named this stratigraphic unit the "Long Pine Formation" for exposures along U. S. Highway 20 near Long Pine, Nebraska, erroneously interpreting these sediments as glacial outwash. In effect, however, the Broadwater Formation (Fig. 9), named in the Nebraska Panhandle by Schultz and Stout (1945), and the "Long Pine Formation" of Skinner and Hibbard (1972) (Fig. 16) are the deposits of the same late Pliocene-early Pleistocene fluvial system (Swinehart and Diffendal, 1998). Swinehart et al. (1985) and Swinehart and Diffendal (1998) considered the gravels that trend north-northeastward from Morrill County in the Nebraska Panhandle into the field trip area and beyond to be sourced from southeastern Wyoming and interpreted them to represent a paleodrainage emerging from the Laramie Mountains, nearly 300 mi (480 km) west-southwest of the present field trip area. The Broadwater Formation, where present, is an important part of the High Plains aquifer.

Broadwater Formation gravels are neither present along the entire length of the Niobrara River Valley nor are they uniformly fossiliferous. Horse, giant camel, llama, peccary, four-tusked elephant, sloth, deer, and saber-toothed cat remains have been recovered from the D&L Sand and Gravel Pit and all indications suggest that these animals inhabited grassland biomes that were widespread in the developing Great Plains by the late Pliocene approximately 2.5 to 3.0 million years ago, during the late Blancan NALMA. The absence of giant tortoise fossils in the Broadwater Formation compared to their abundance in the Valentine and Ash Hollow formations suggests that temperatures frequently dropped below freezing for significant portions of time by that time in Nebraska (Holman, 1971).

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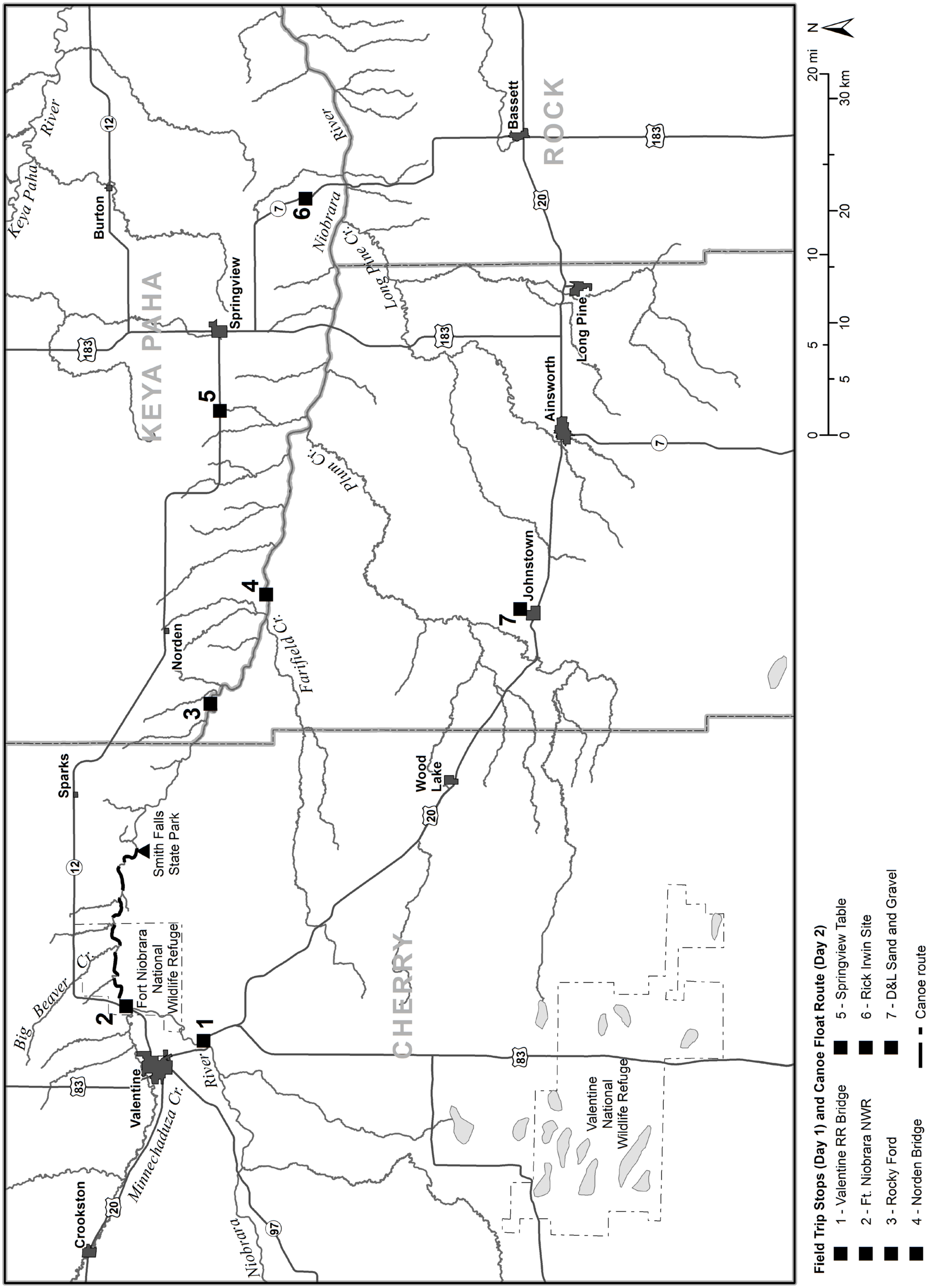

Figure 1. Area and route of field trip.

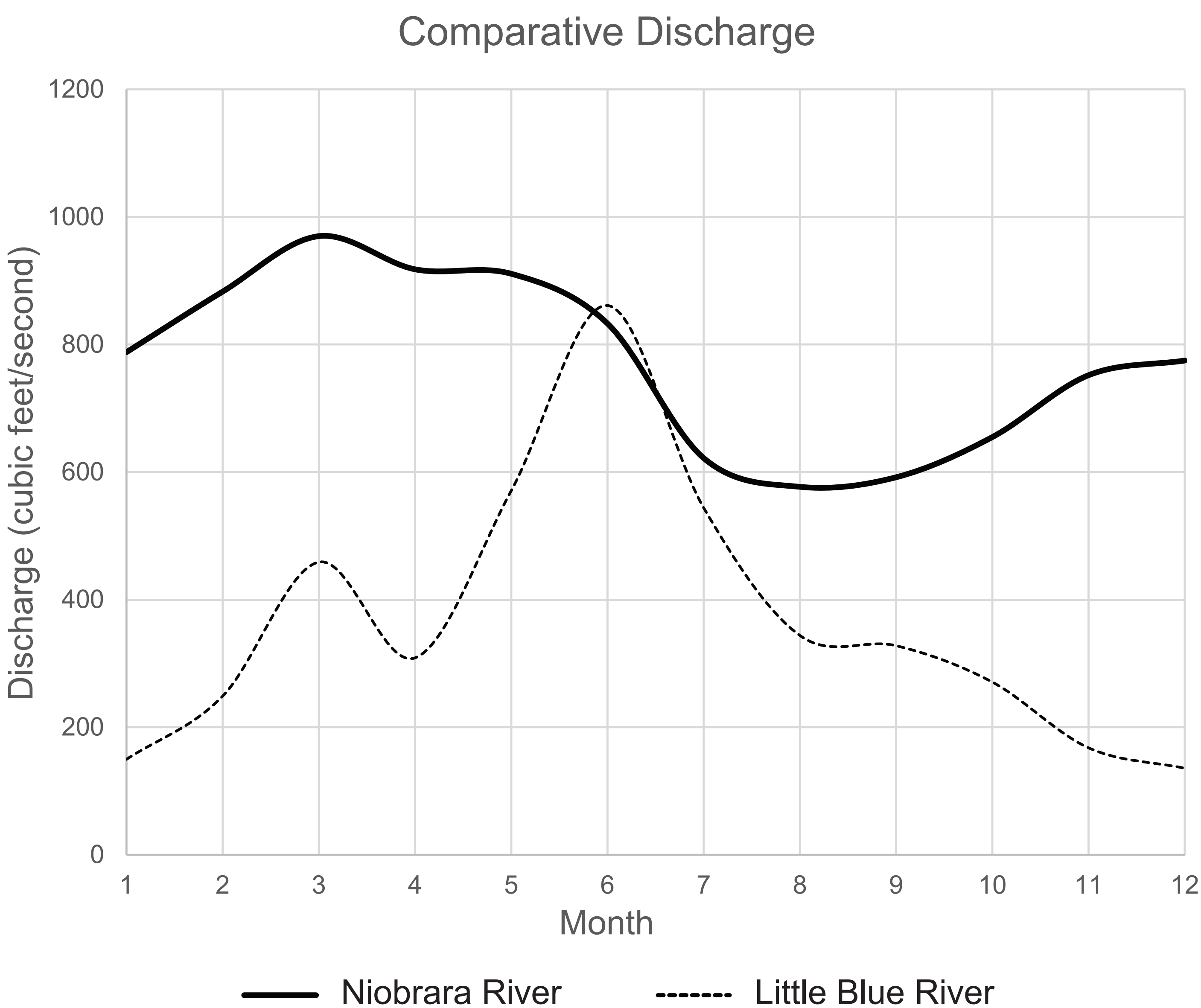

Figure 2. Comparative annual discharge hydrographs for Niobrara and Little Blue rivers.

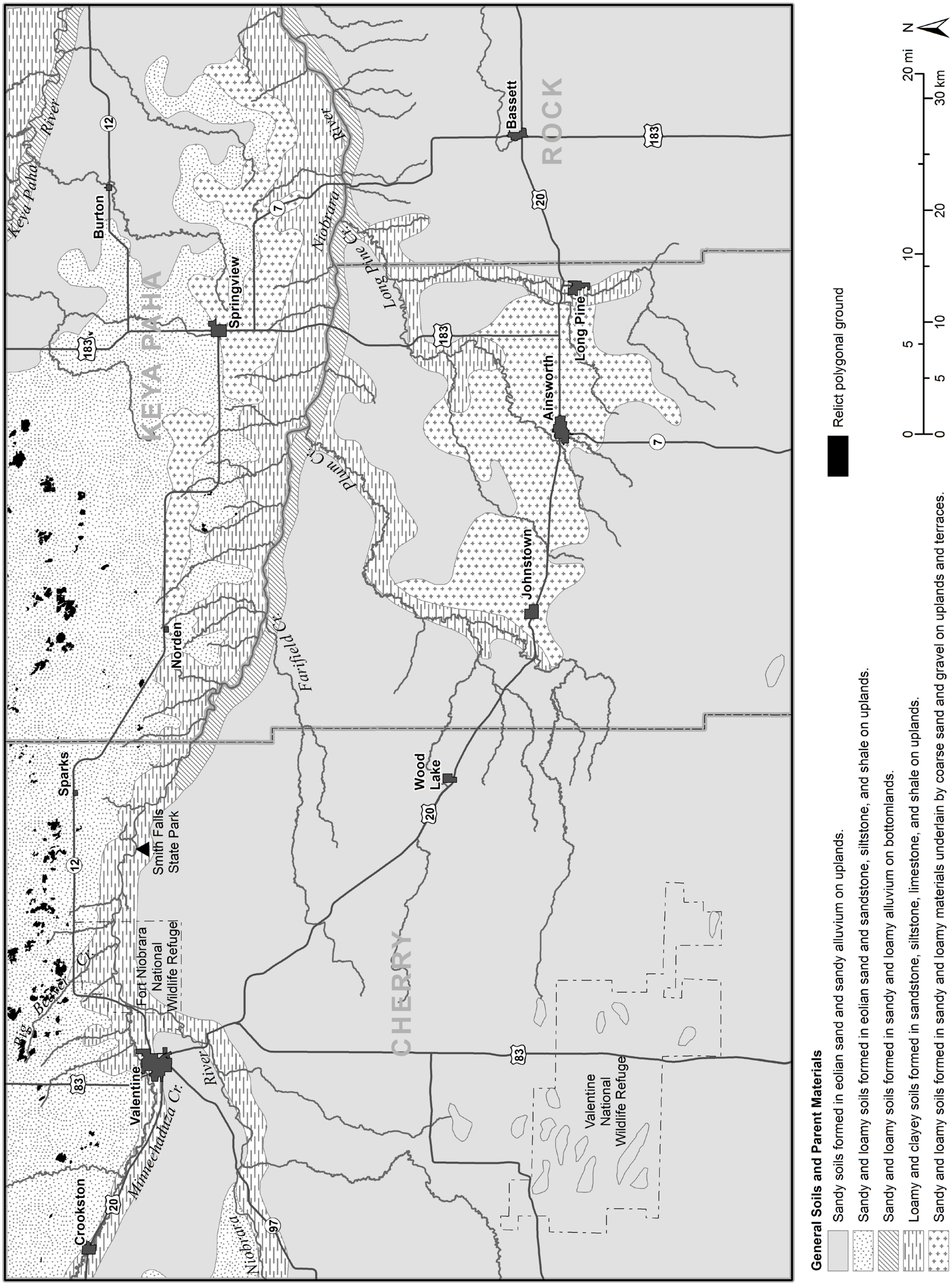

Figure 3. General soils and parent materials and location of relict polygonal ground

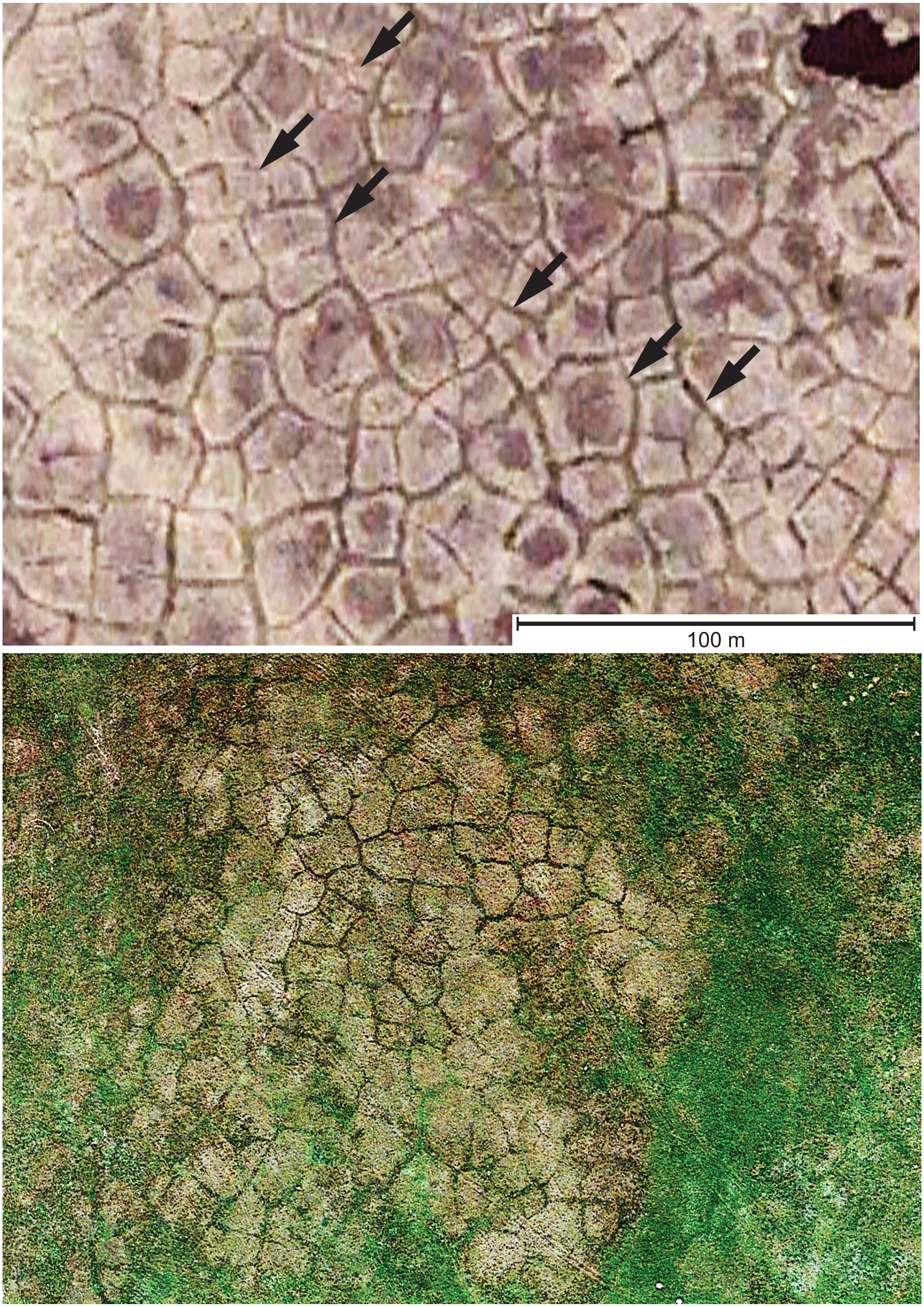

Figure 4. Polygonal ground in extant permafrost near Barrow, Alaska (above) and relict polygonal ground north of the Niobrara River in field trip area.

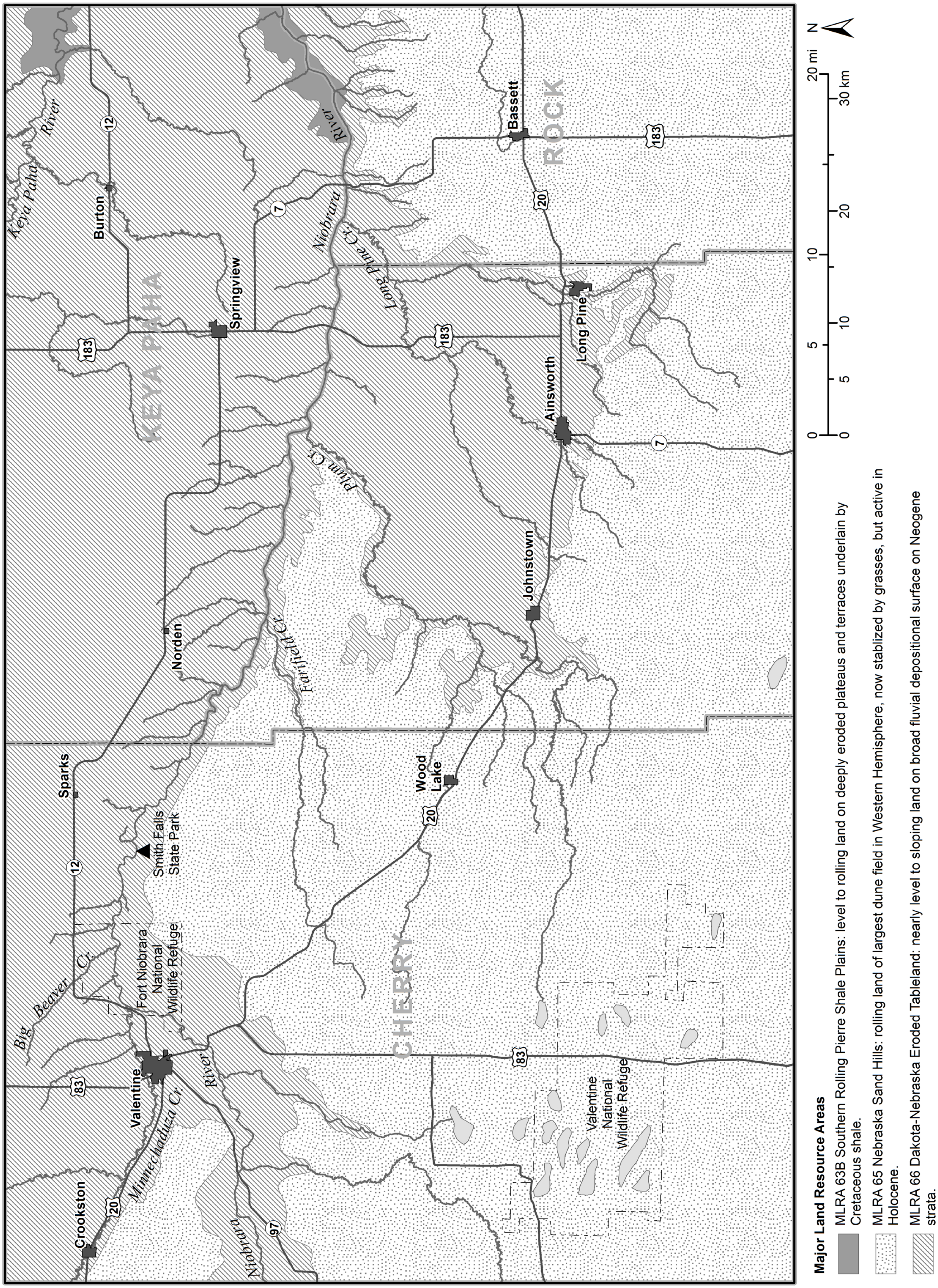

Figure 5. Major Land Resources Area (MLRAs) in field trip area.

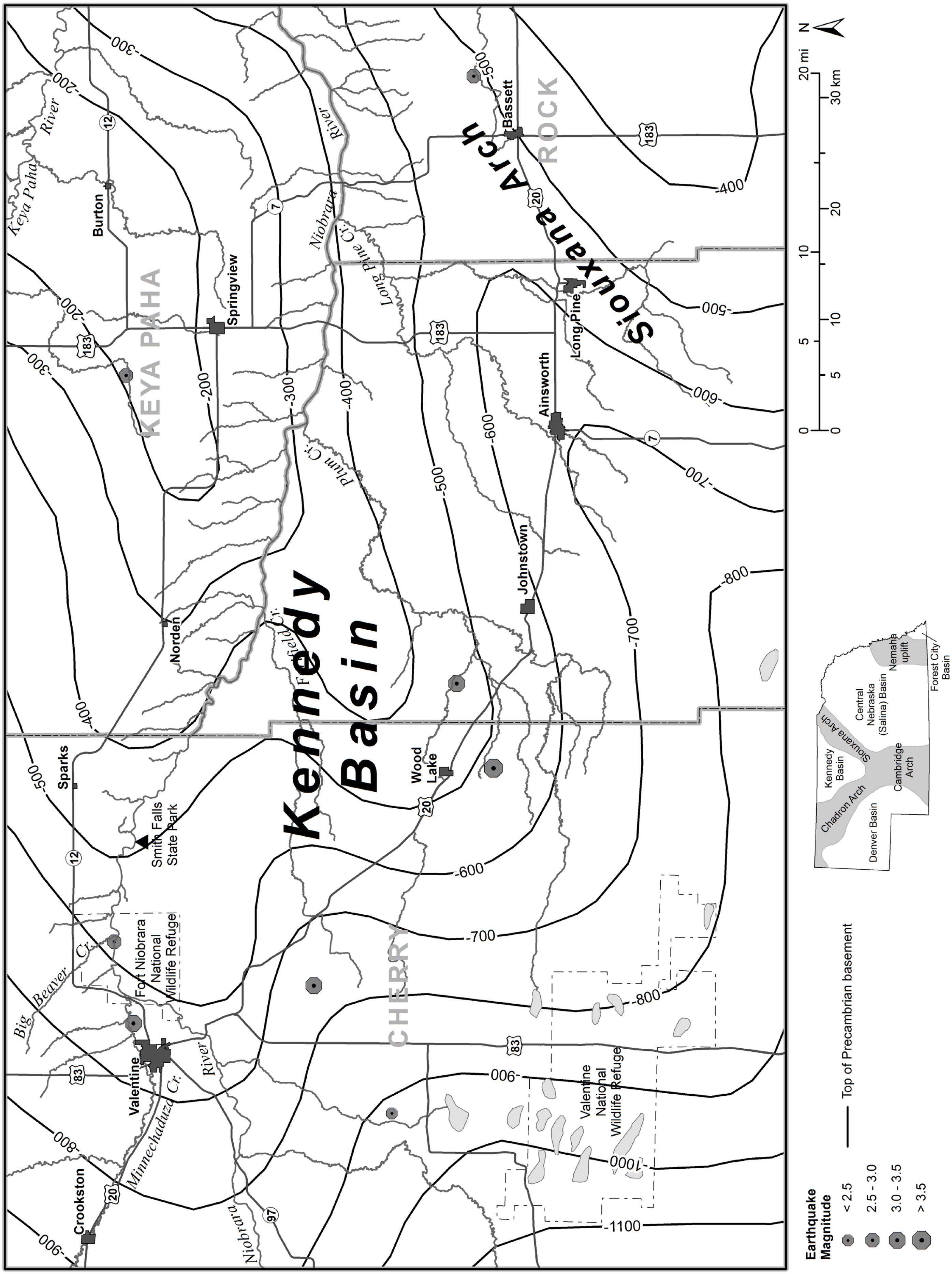

Figure 6. Basement elevations, structure, and historical earthquakes.

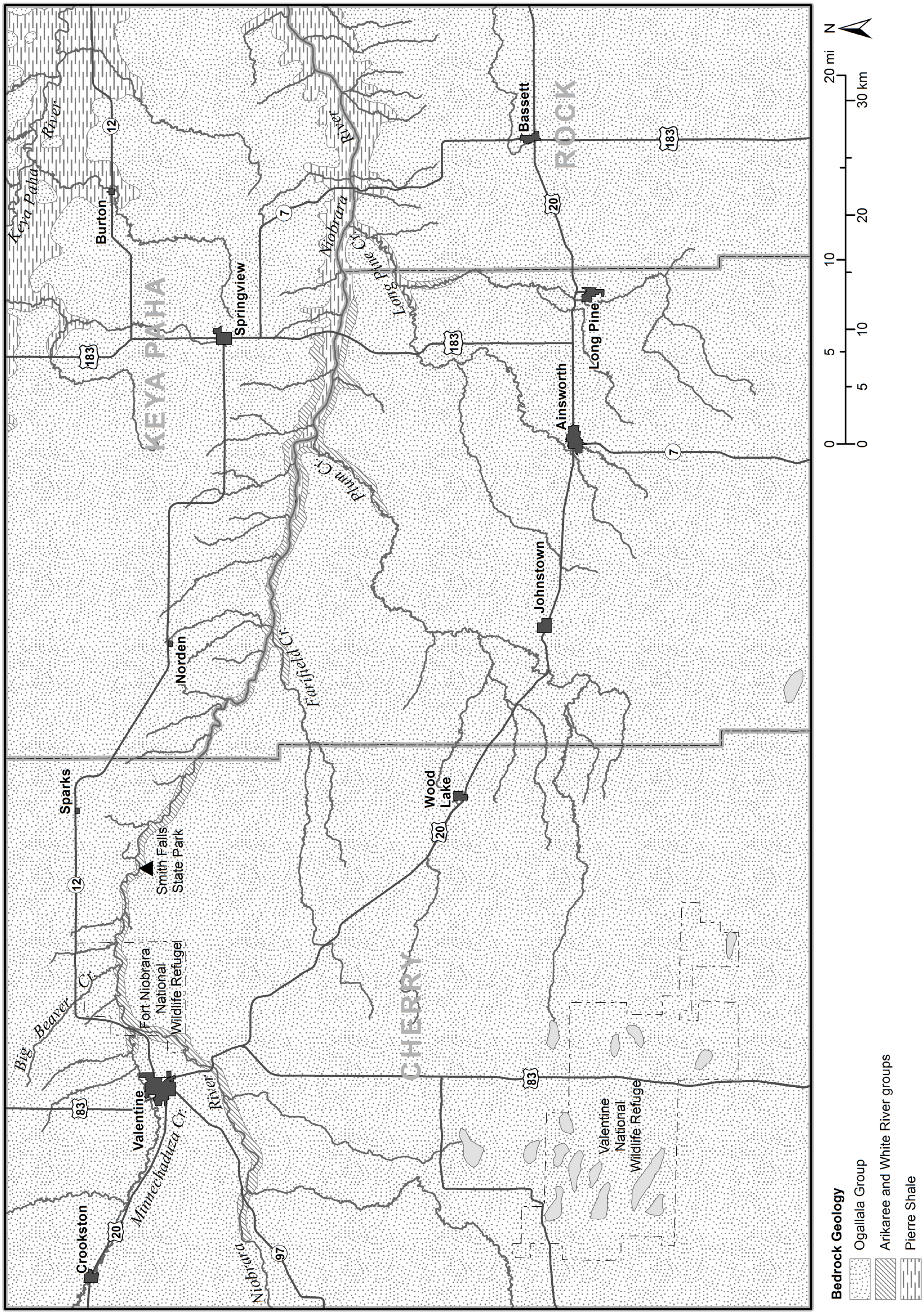

Figure 7. Bedrock geology.

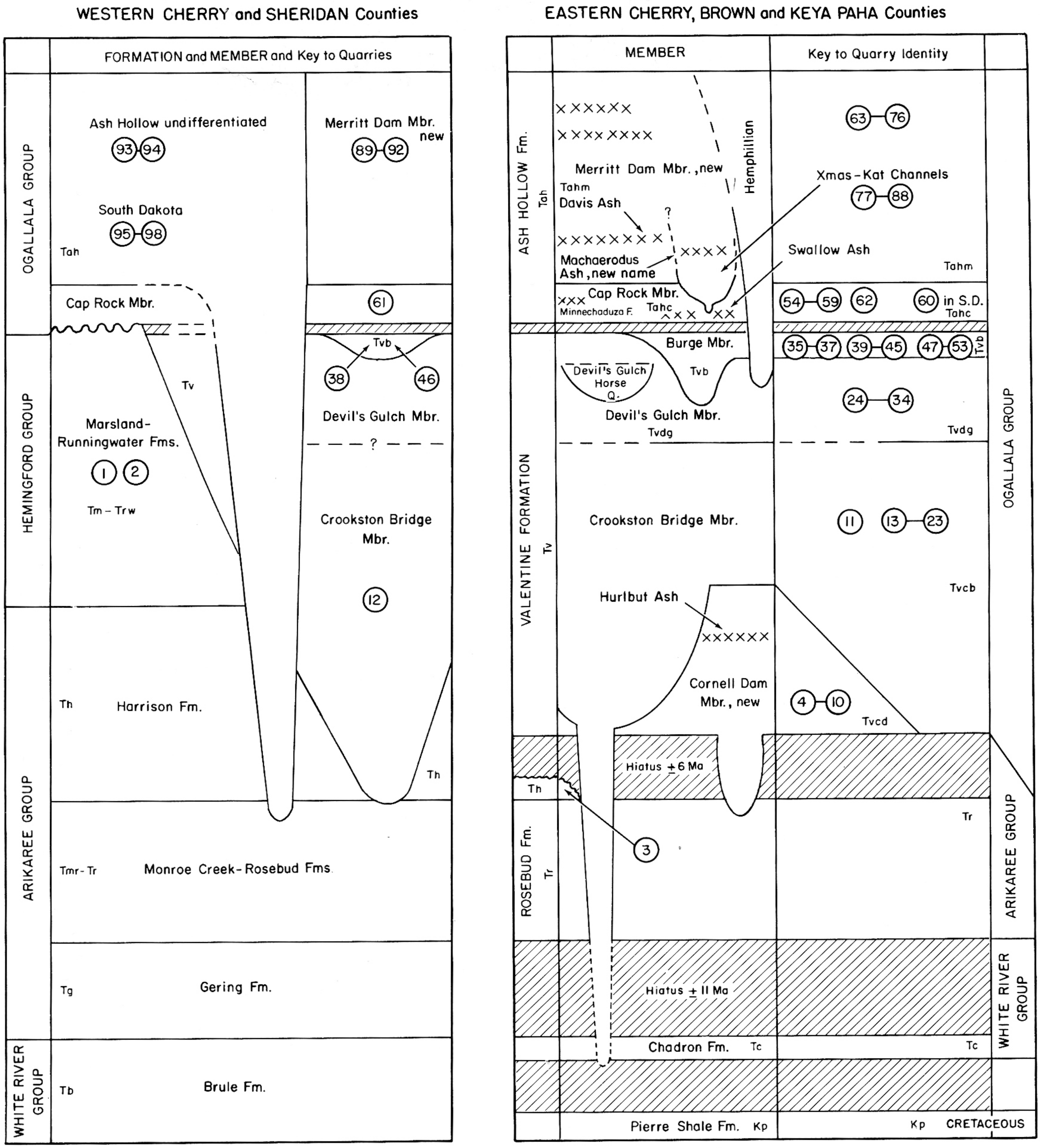

Figure 8. Composite section of exposed Cenozoic strata in central Niobrara River Valley from Skinner and Johnson (1984).

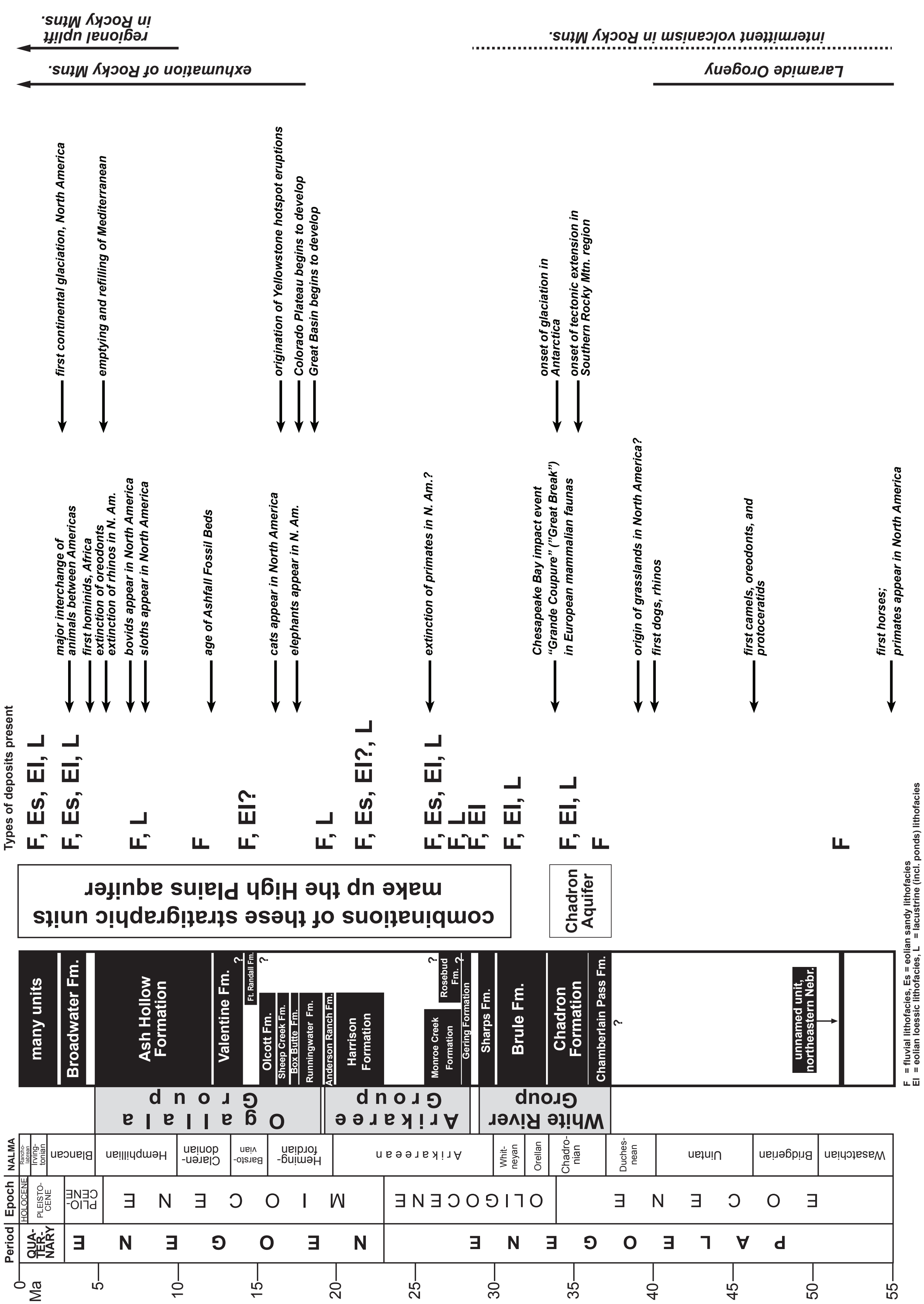

Figure 9. Composite time-stratigraphic chart of Cenozoic strata in Nebraska, composition of High Plains aquifer, and important events during Cenozoic Era.

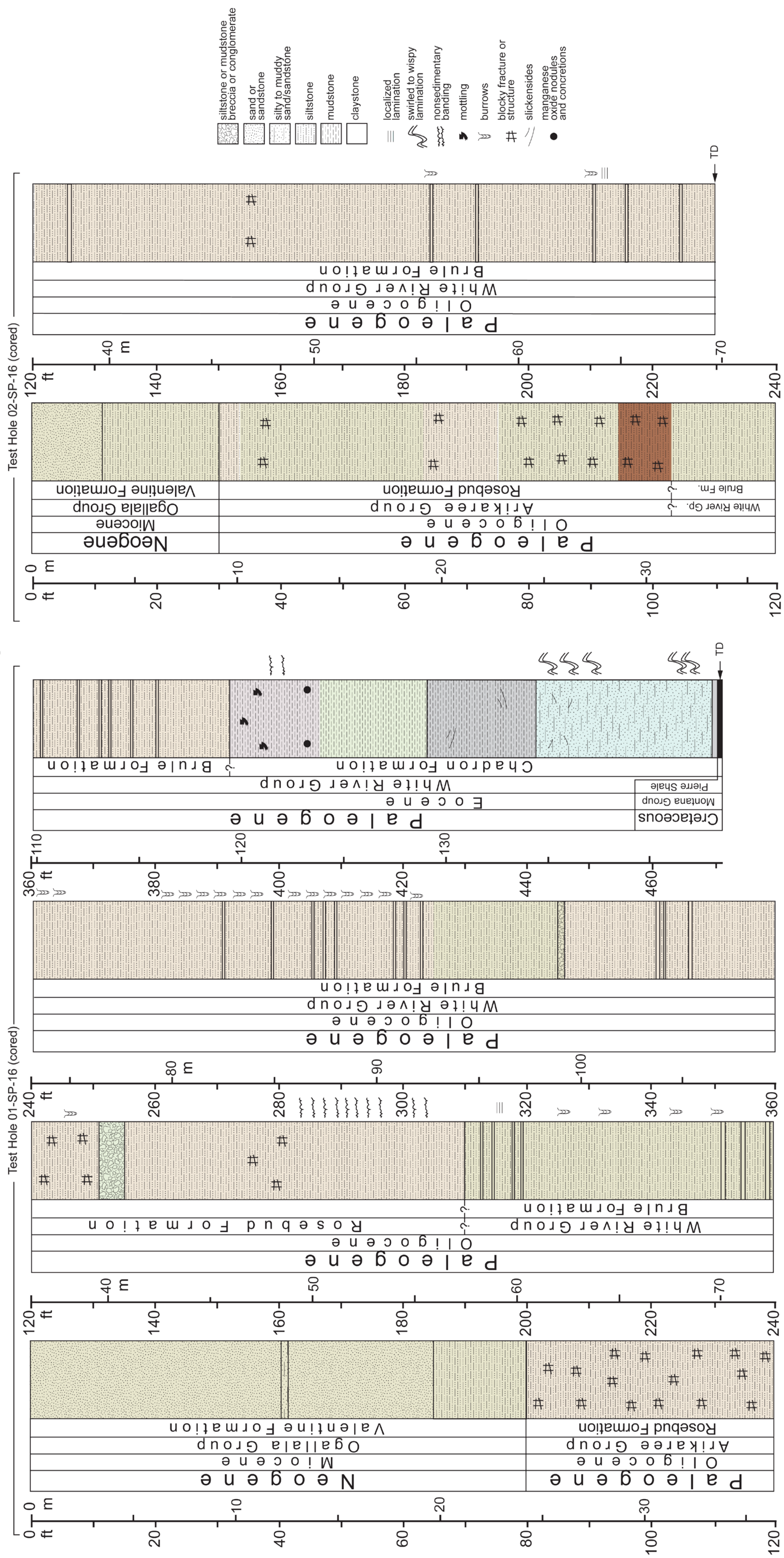

Figure 10. Conservation and Survey coreholes drilled in Sparks area in 2016.

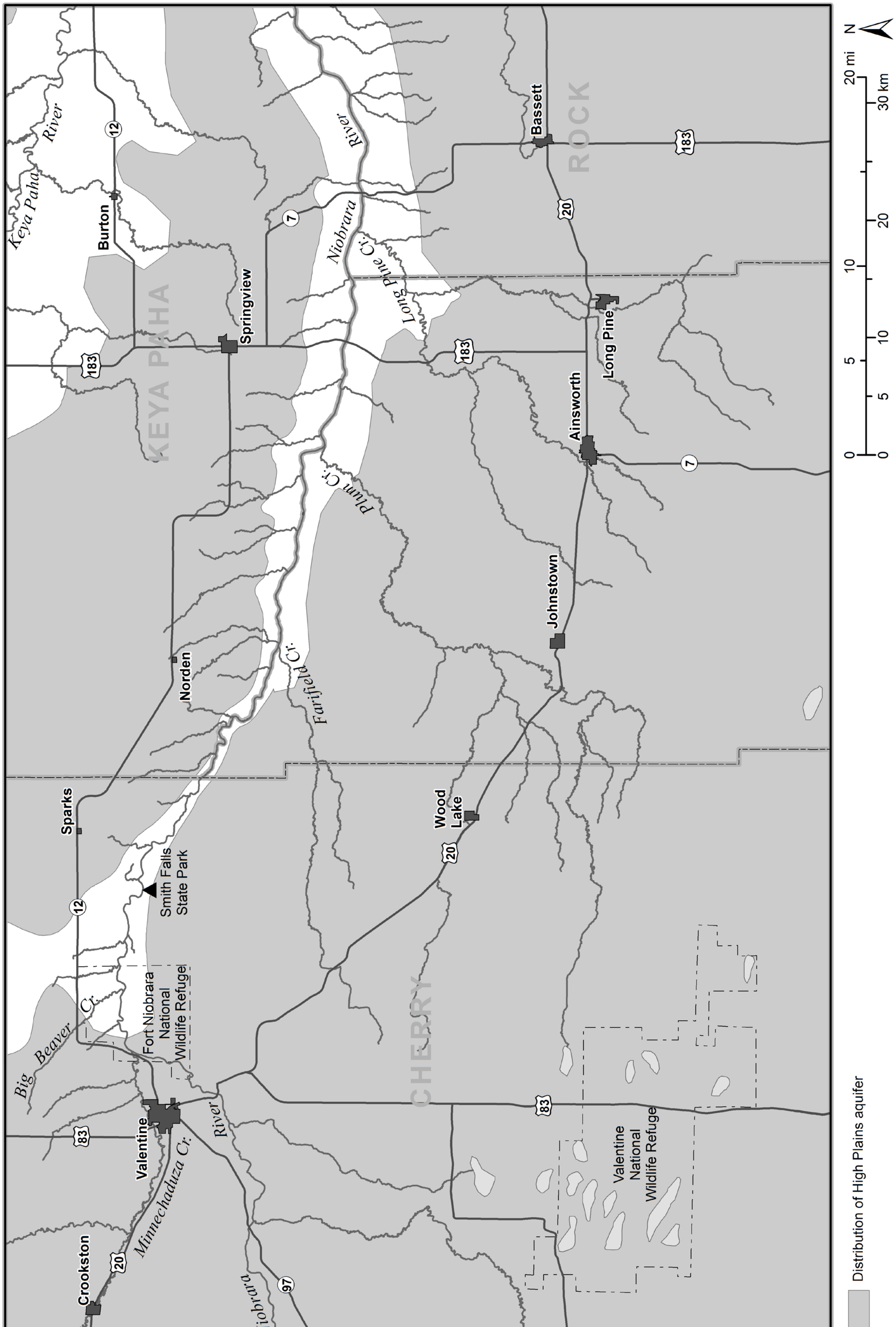

Figure 11. Distribution of High Plains aquifer.

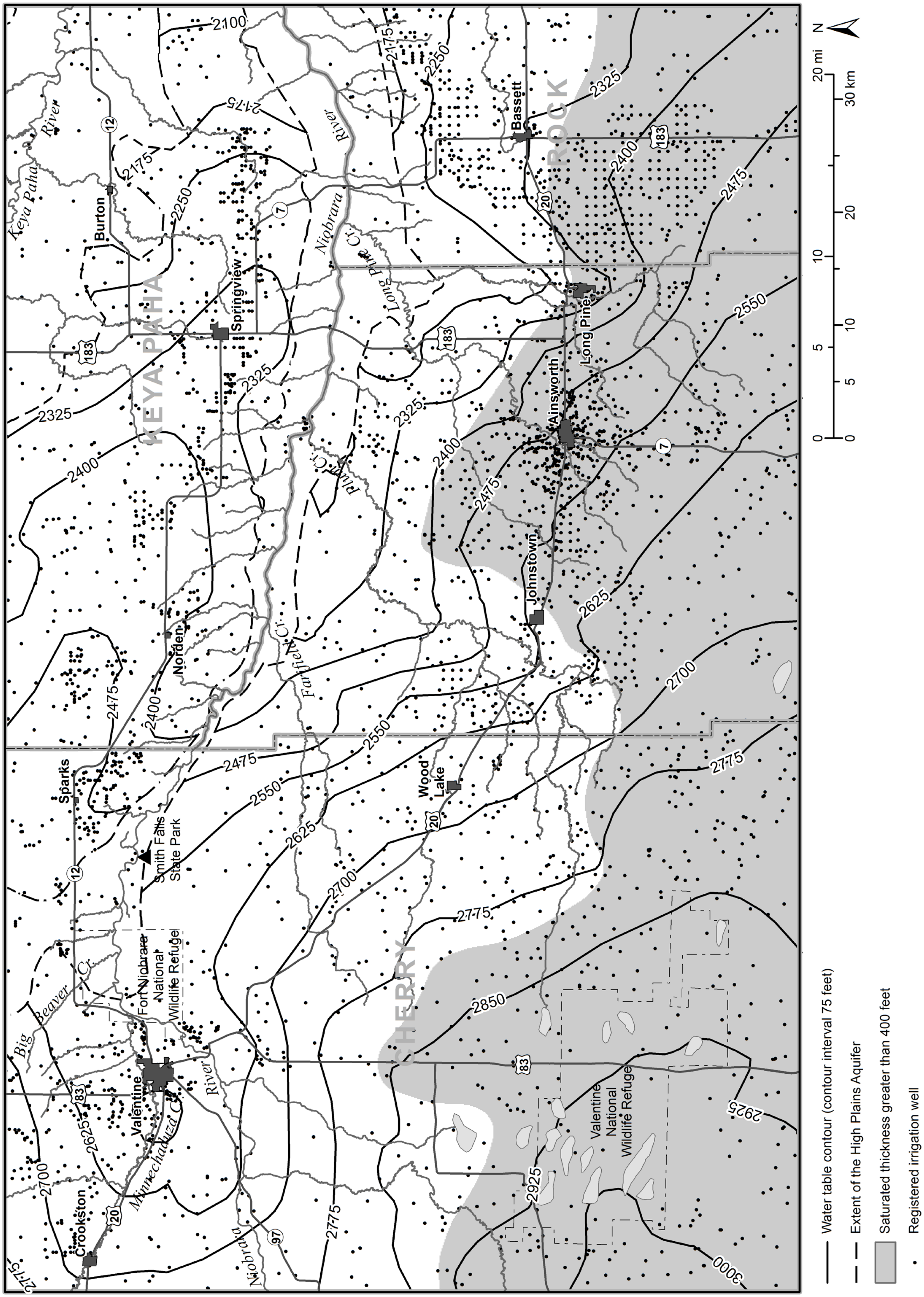

Figure 12. Distribution of registered irrigation wells and parameters of High Plains aquifer.

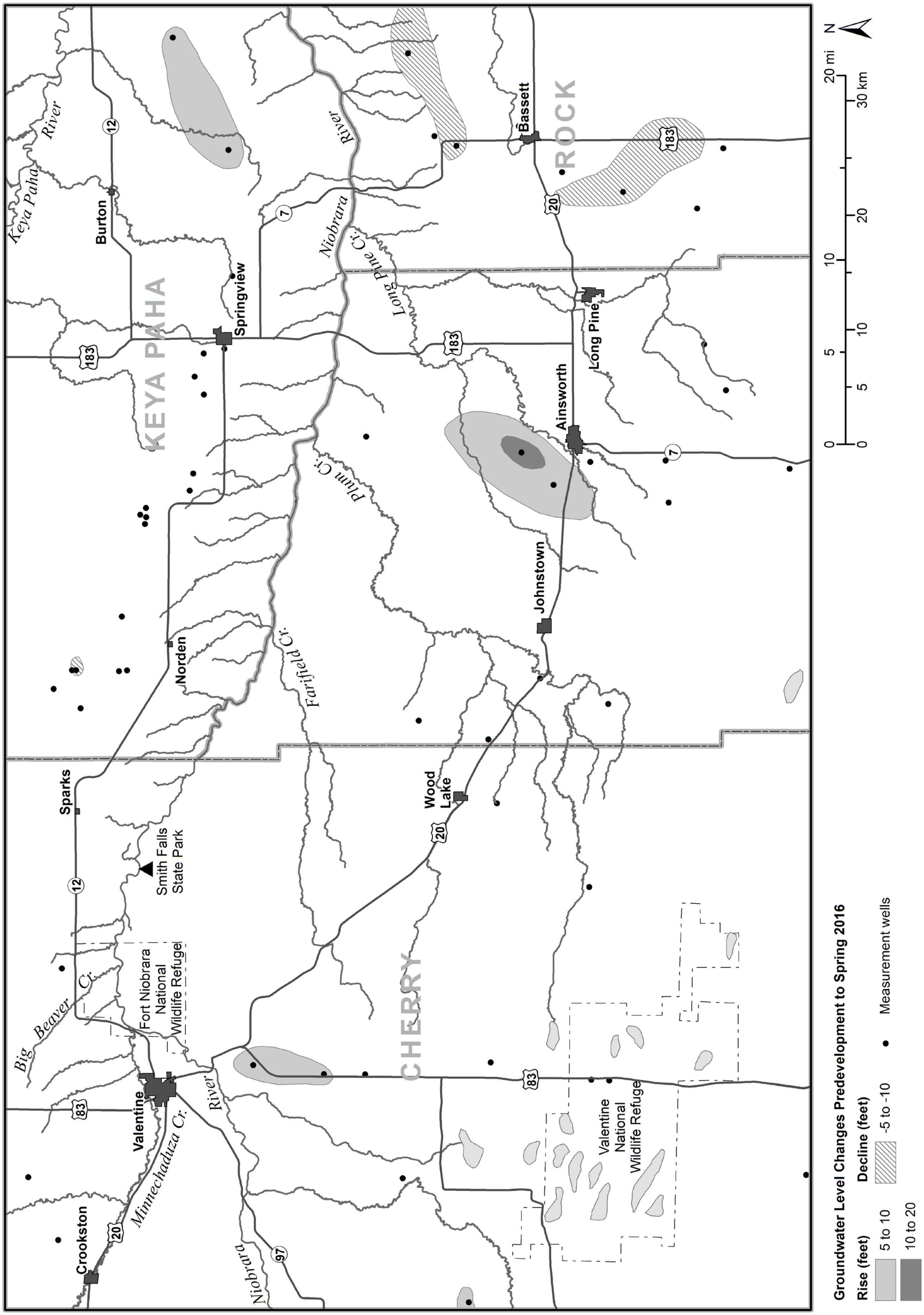

Figure 13. Groundwater level changes, predevelopment to 2016.

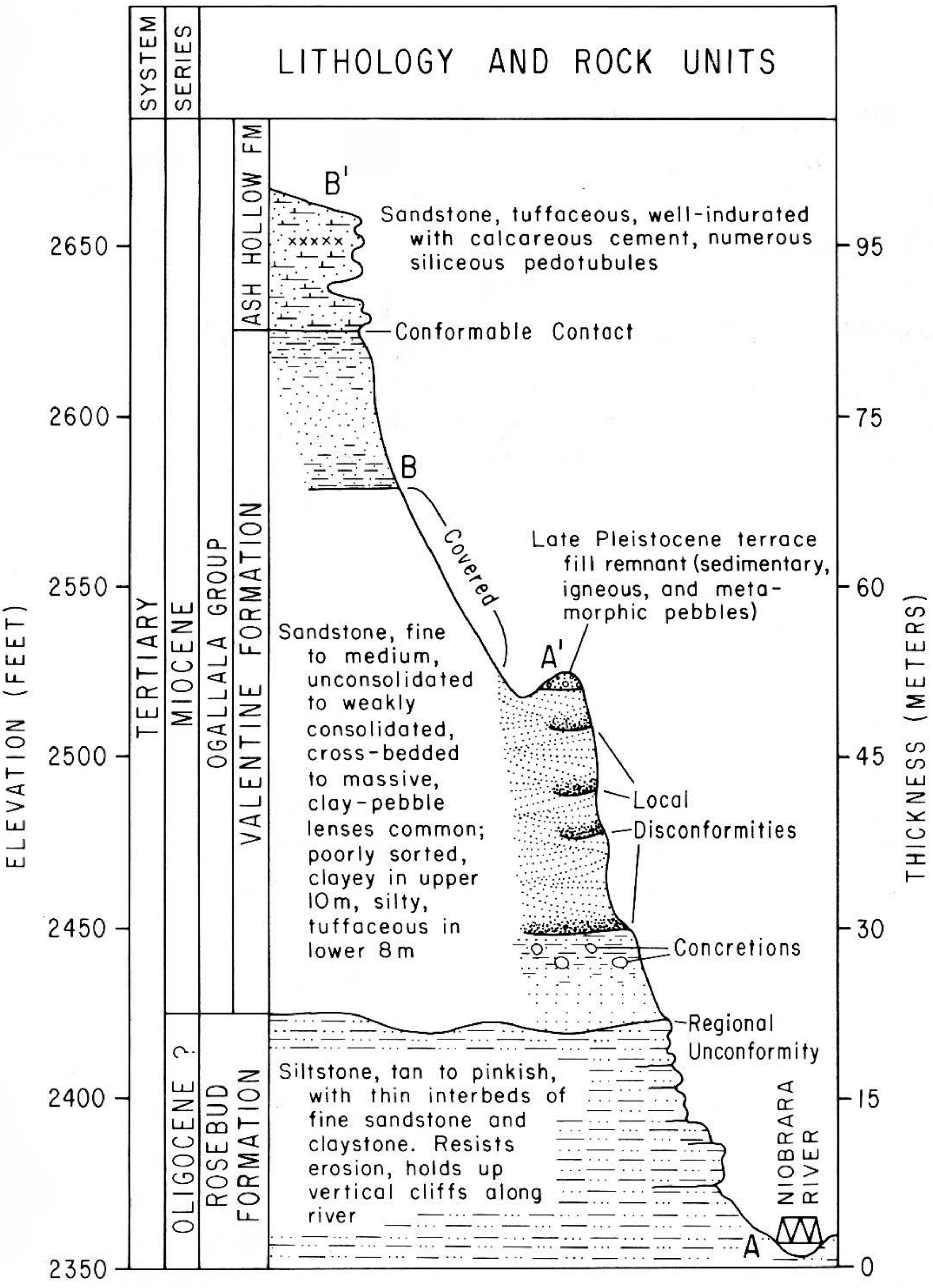

Figure 14. Generalized stratigraphic column for Fort Niobrara National Wildlife Refuge, from Voorhies (1987).

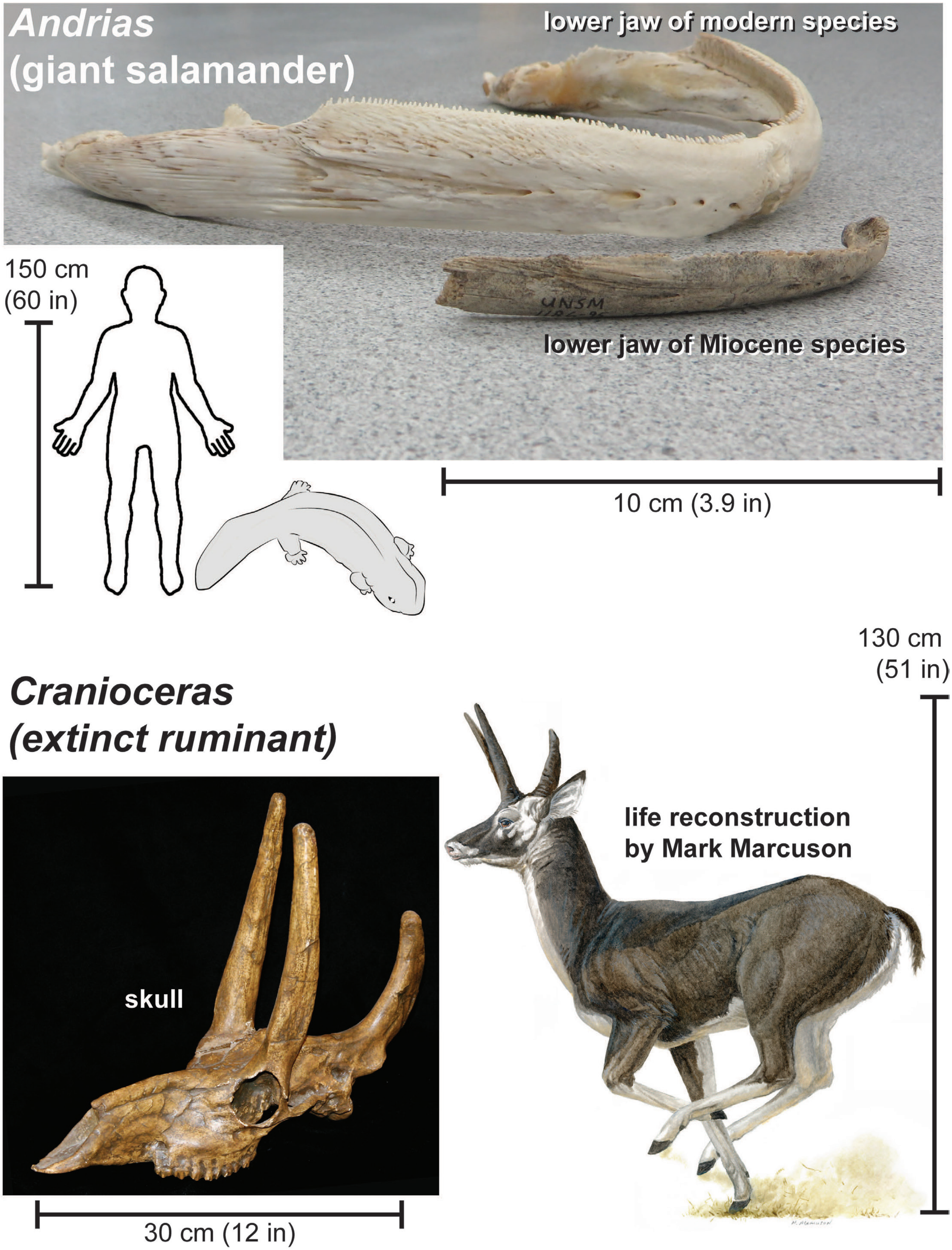

Figure 15. Giant salamander (above) and extinct ruminant (below) from Valentine Formation.

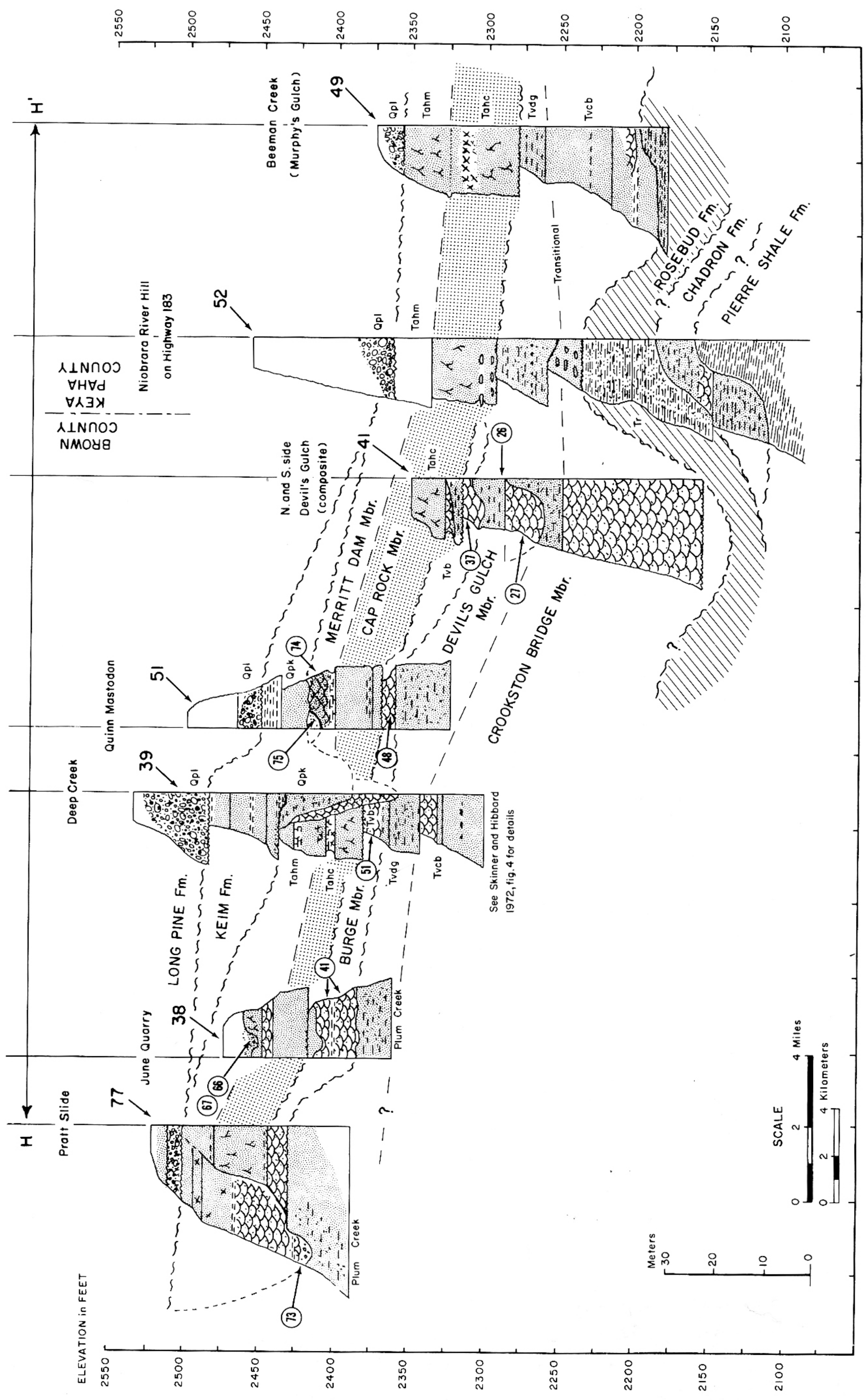

Figure 16. Cross-section from Skinner and Johnson (1984, fig. 37) showing detailed sections of stratigraphic units near Springview.

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